

# THE CRITICAL TEMPERATURE OF THE CHICKEN<sup>1</sup>

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## INTRODUCTION

In the course of a somewhat extensive series of investigations of the energy metabolism of chickens and of the net-energy value of feeds for chickens, it became necessary to determine the critical temperature of this animal—that is, the environmental temperature at and below which the heat production of the fasting resting animal will increase to prevent a lowering of body temperature.

## REVIEW OF LITERATURE

The first reported investigation of the critical temperature of the chicken appears to be that of Regnault and Reiset, published in 1850 (10)<sup>2</sup>. These results, recomputed by Gerhartz (3), indicate a continuous decrease in the oxygen consumption of fasting hens as the environmental temperature increases from 19° to 23° C. However, there appears to be no assurance that the activity of the birds was sufficiently controlled in these experiments, a requisite to investigations of energy metabolism the importance of which was not appreciated at this early date.

Gerhartz himself (3) has published respiration data from two hens exposed in a fasting condition to external temperatures ranging from 21° to 32° C. The computed oxygen consumption per kilogram body weight per hour, when plotted against temperature, indicated a sharp drop in metabolism at about 23°, followed by a rapid rise at lower temperatures. This temperature was considered to be the critical temperature of the hen. There are, however, several objections to this interpretation. The hens had fasted for only 13 to 24 hours. In the writers' experiments it was found that the effect of food on heat production may extend over a much longer period. Hence, Gerhartz's hens can not be considered as having been in the postabsorptive condition, a condition obviously necessary to a determination of the critical temperature. Furthermore, the sharp rise in oxygen consumption shown by Gerhartz's curve for temperatures lower than 23° may be an effect of individuality rather than of temperature, since the values for 23° and above were obtained from hen 1, while the values below 23° were obtained from hen 2. It is questionable whether values obtained from two animals at distinct temperature ranges can be safely compared in this way.

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<sup>2</sup> Reference is made by number (italic) to "Literature cited," p. 557.

Later investigations on the energy metabolism of geese (6), ducks (7), and other birds (4), aside from indicating more or less certainly a stimulating effect of low temperatures on heat production, have not contributed any definite information as to the critical temperatures of birds.

#### METHODS AND APPARATUS

In the present study, the respiratory exchange of the hens was determined by means of the gravimetric method of Haldane (5). By this method, open circuit in principle, the animal chamber is ventilated with a stream of air that has been rendered dry and free of carbon dioxide by passage through sulphuric acid and caustic alkali (or soda lime). The outgoing air is again passed through these reagents in appropriate containers. The carbon dioxide pro-

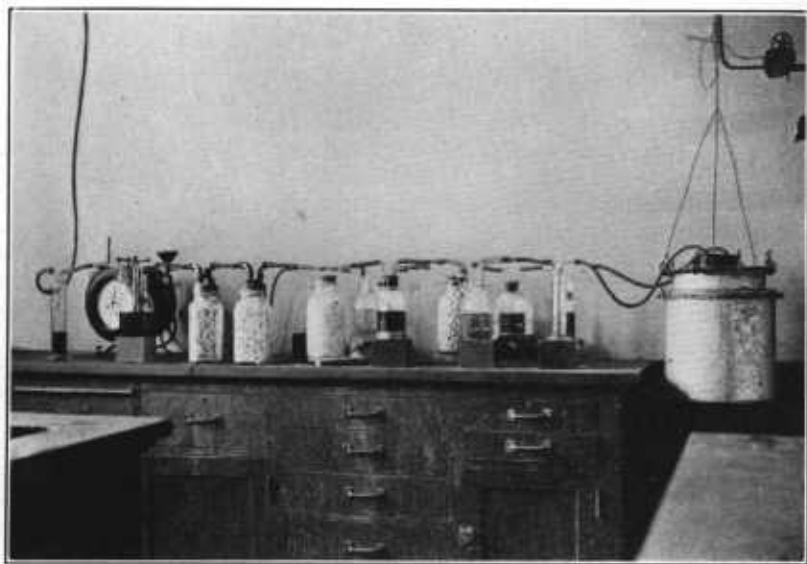


FIG. 1.—Apparatus used in critical temperature studies

duction of the animal is measured by the increase in weight of the caustic alkali bottle and of the sulphuric acid container following, while the oxygen consumption is measured by the total increase in weight of the animal chamber and the entire outgoing chain of bottles. An apparatus such as was used by the writers in much of their work with chickens is shown in Figure 1.

Since this particular investigation deals entirely with fasting birds, in which, according to the writers' observation, the respiratory quotient is fairly constant at 0.70 to 0.73, the oxygen determination was dispensed with and variations in heat production were measured by variations in the production of carbon dioxide. The outgoing chain consisted of a Williams bottle next to the chamber, for the removal of water, and a small bottle filled with caustic soda ("shell caustic"), followed by a small gas-washing bottle containing sulphuric acid.

The two last-mentioned containers were much smaller than those illustrated, since the experiments were less than one hour in duration. The smaller size permitted more accurate weighing. Between the Williams bottle and the caustic-soda bottle was a two-way stopcock leading either to the caustic-soda bottle or to the pump directly by way of a rubber tube. By manipulation of this stopcock, the outgoing air could be drawn through the carbon dioxide absorption chain or could be diverted from it.

The experiments were conducted according to the following general plan: All the hens were allowed to fast for at least 41 to 48 hours, since, according to the writers' observation, this length of time is required for the postabsorptive condition to be reached after a normal meal. To avoid any possibility of error, most of the hens were allowed to fast for 72 hours. As soon as a hen was placed in the animal chamber the chamber was sealed with paraffin, ventilation was started, and the stopcock on the outgoing chain was so turned that the air passed directly to the pump. The animal chamber was then brought to the desired temperature by exposing it to a draft of cold air, aided if necessary by the placing of ice on the top of the chamber. The temperature of the air as it emerged from the chamber was taken as the environmental temperature of the hen. The collection of carbon dioxide was not started until the hen had been exposed for at least 30 minutes to the experimental temperature.

In such an investigation as this it is essential to the proper interpretation of the results that the activity of the hen shall be at the lowest possible minimum. This was assured in two ways. The chamber used was just large enough to contain the hen snugly. Any considerable moving around was thus rendered impossible. Furthermore, the hen was in complete darkness, a condition known to favor quietness in hens. For the detection of small movements of the hen, the animal chamber was suspended from a spring. (Fig. 1.) By noting the up and down movement of the chamber, or, better yet, by placing the hand beneath it, slight movements of the hen could be detected. In all of the experiments, the hens were completely at rest, in so far as this condition could be determined by the method used. If, after the air was permitted to pass into the carbon dioxide absorption bottle, any appreciable movement of the hen was noted, the air was immediately diverted to the pump, and was not again admitted to the caustic soda bottle for at least five minutes after the hen had come to complete rest. The time was noted at each turning of the stopcock, in order to obtain the total time of collection, and the rate of ventilation, as measured by a gas meter, was kept constant throughout the period of observation at approximately 3 liters per minute. With these precautions, it is believed that the results obtained possess a definite significance.

#### EXPERIMENTAL DATA

Twelve Rhode Island Red hens, ranging in weight from about 4 pounds to over 6 pounds, were used in this investigation. Thirty-six observations were made upon these hens, with the results shown in Table 1.

TABLE 1.—The carbon dioxide production of hens at different external temperatures

Experiment No.	Hen No.	Date of test	Hours of fast	Body weight	Carbon dioxide production per minute at temperatures of—								
					85° F.	80° F.	75° F.	70° F.	65° F.	60° F.	55° F.	50° F.	45° F.
		1925		Gm.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.
1	2429	Jan. 2	41	2,026			26.8	27.0	23.6	24.0	26.0		
2	2158	Jan. 5	46	2,325				22.5	24.4	30.1	36.0		
3	2420	Jan. 6	46	2,717				26.1	23.1	28.8	30.9		
4	2089	Jan. 7	48	2,500			25.4	26.0	24.8	24.0			
5	2143	Jan. 8	48	2,997			29.1	24.2		24.0			
6	2117	Jan. 9	48	2,233				21.4	21.9	25.6	27.9		
7	2429	Jan. 10	48	1,927					21.9		22.9		
8	2084	Jan. 12	72	2,086			24.5	20.9	23.0				
9	2058	Jan. 14	72	2,509		25.1	30.7						
10	2053	Jan. 15	72	2,710			24.5	27.4	25.9	24.0			
11	2013	Jan. 16	72	2,665			27.2	23.3	28.5		30.0		
12	2000	Jan. 19	72	1,850			19.2	13.8	21.3		22.9		
13	2009	Jan. 20	72	2,485			20.0				24.8		
14	2158	Jan. 21	72	2,412			19.0				22.4		
15	2420	Jan. 22	72	2,788			25.0				26.5		
16	2089	Jan. 23	72	2,625			24.8				30.0		
17	2143	Jan. 26	72	3,017			20.0		22.5				
18	2117	Jan. 27	72	2,347			17.0		25.4				
19	2084	Jan. 28	72	2,220			22.8		20.5				
20	2058	Jan. 29	72	2,595			21.4		22.0				
21	2053	Jan. 30	72	2,717			24.4		24.2				
22	2013	Feb. 2	72	2,749			25.9						
23	2420	Feb. 3	72	2,809			17.6		21.1				
24	2000	Feb. 4	72	1,905			17.5		14.4				
25	2009	Feb. 5	72	2,562	20.7		24.7		24.2				
26	2158	Feb. 6	72	2,657	20.0		22.7						
27	2429	Feb. 9	72	2,145	24.3		21.1						
28	2089	Feb. 10	72	2,685	21.0		21.2						
29	2143	Feb. 11	72	3,042	27.5		22.5						
30	2117	Feb. 12	72	2,430	23.0		18.7						
31	2084	Feb. 13	72	2,387			18.4						
32	2058	Feb. 16	72	2,745			19.5						
33	2053	Feb. 17	72	2,875				24.4		29.2			
34	2013	Feb. 18	72	2,970				19.2		28.8			
35	2420	Feb. 19	72	2,940					30.6		30.7		
36	2000	Feb. 20	72	2,062					28.0		35.8		
										17.4		24.8	
										19.2		24.0	
										29.8		26.1	
										26.4		29.5	
										24.3	29.7	37.0	
										27.7			
										30.0		30.4	
										28.5		35.3	
										26.6		26.9	
										25.9		31.4	
										24.7		26.4	
										22.7		27.2	
										24.7		28.1	

Environmental temperatures ranging from 45° to 85° F. were imposed, and in many of the experiments duplicate or triplicate determinations of the carbon dioxide production were made at each of the temperatures used. The order in which the different temperatures were imposed is not indicated in the table, since, from a study of the records, it did not appear to be a matter of consequence.

Evidently the individual experiments were not planned—at least in most cases—in such a way that the exact location of the critical

temperature could be determined. The most that any one experiment indicates is that the desired temperature is above or below a given point. Therefore in their most complete interpretation, they must be considered in the aggregate. The experiments have been summarized in Table 2, according to the following scheme:

TABLE 2.—*The number of experiments which indicate the location of the critical temperature either above or below the environmental temperatures imposed*

Temperature imposed	Number of experiments locating the critical temperature—	
	Below the temperature imposed	Above the temperature imposed
° F.		
45	0	23
50	1	21
55	3	17
60	6	12
65	12	8
70	13	2
75	14	2

1. If the results in experiments involving only two temperatures indicate, more or less certainly, that the production of carbon dioxide per minute was greater at the lower than at the higher temperature, they are interpreted to mean that the critical temperature is above the lowest of the two temperatures. Its location with reference to the highest temperature can not be inferred. In experiment 13, for example, the two observations at 75° F., i. e., 19 and 20 mgm., are lower than those at 55°, i. e., 24.8 and 22.4 mgm. Hence, the critical temperature is evidently above 55°, but whether it is above or below 75° the results do not indicate. Since, in this experiment, the critical temperature is above 55°, it must also be above 50° and 45° and is so listed in Table 2, where it is entered at these three temperatures.

2. Similarly, if a series of continuous observations extending over more than two temperatures indicate a continuous increase in carbon dioxide production with each decrease in temperature, the conclusion is justified that the critical temperature is above the second highest temperature of the series. Experiment 2 is a good example of this type. A continuous increase in carbon dioxide production was observed from 70° to 55° F. It is evident that the critical temperature in this experiment is above 65°, but whether it is above or below 70° can not be decided, since the increase in carbon dioxide production observed may have started either at a point between 65° and 70° or at some point above 70°. In this case, therefore, it can only be concluded that the critical temperature is above 65°, and hence above all lower temperatures. In Table 2, therefore, this experiment is listed as indicating a critical temperature above 65°, 60°, 55°, 50°, and 45°, thus entering the table in five places.

3. If a series of two or more continuous observations at different temperatures shows no significant effect of environmental temperature on carbon dioxide production, the conclusion is justified that the critical temperature is below the lowest temperature of those at which observations were taken. An illustration of such an experiment is afforded by experiment 10, which indicates a critical temperature below 60° F., experiment 16, which indicates a critical

temperature below 65°, and experiment 31, which indicates a critical temperature below 50°. Experiment 10 was used in the construction of Table 2 as indicating a critical temperature below 75°, 70°, 65°, and 60°; experiment 16, as indicating a critical temperature below 65°, and all higher temperatures; and experiment 31, as indicating a critical temperature below 50° and all higher temperatures.

4. If, in a series of observations extending over several temperatures, it appears that the carbon dioxide production of the hen increases somewhere between two of the temperatures chosen, it is inferred that the critical temperature is similarly located. Experiment 6 represents such a case, and in the construction of Table 2 is taken as indicating a critical temperature above 60°, 55°, 50°, and 45°, and below 75°, 70°, and 65°, thus entering the table at seven places. Experiment 11 is similar.

5. In a few of the experiments, a tendency to an increase in carbon dioxide production at the higher temperatures is evident. Since such an increase bears no relation to the critical temperature, it is not considered in the construction of Table 2. Such an increase may be noted in experiments 5, 11, and 27.

Having considered the method used in summarizing and evaluating the results in Table 1, the results given in Table 2 may now be studied with the idea of obtaining an average value for the critical temperature of the chicken. None of the experiments indicated a critical temperature below 45° F., while 23 indicated one above this temperature. For 50°, one experiment pointed to a critical temperature below, while 21 pointed to a critical temperature above. The figures in the two columns at the right approach equality between 60° and 65°. For observations taken above 65°, the evidence points unmistakably to the conclusion that the critical temperature is below this range rather than above. The evidence as a whole, therefore, may be taken to point to an average critical temperature for the Rhode Island Red hen of approximately 62° F. or 16.5° C. Since these birds were taken from the university poultry farm in the middle of winter, this critical temperature may be considered as applying to chickens under winter conditions of feathering and under the condition of low humidity obtaining in the animal chamber.

This average critical temperature of 16.5° C. for the winter-feathered Rhode Island Red hen may be compared with the critical temperature of about 21° C. for the pig, as recently determined by Capstick and Wood (1). Forbes and his associates (2) have reported a critical temperature greater than 18.3° C. for a steer with closely shorn hair and less than 15.5° for a steer carrying a full coat of hair. Morgulis (9) determined the critical temperature of a female Irish terrier before and after clipping to be, respectively, between 13.6° and 15.1°, and between 23.8° and 26.5° C. The critical temperature of the goat, determined by Magee, (8) is not comparable to the values above given, since the animal was not fasting but was receiving approximately a maintenance ration. Under this condition, the critical temperature appeared to lie between 12.7° and 21.1° C. In the fasting state the temperature would be higher still.

A study of the individual reactions of the 12 hens used in the metabolism experiments herein reported reveals considerable differences. The best judgment of the writers as to the location of the critical temperatures of the individual birds is given in Table 3.

TABLE 3.—*Probable location of the critical temperatures of the individual hens*

Hen No.	Number of experiments	Probable location of critical temperature (° F.)
2429	2	Below 55.
2158	3	Between 65 and 75.
2420	4	Above 65.
2089	3	Inconclusive.
2058	3	Above 75.
2013	3	Between 65 and 75.
2000	3	Above 65.
2009	2	Above 75.
2084	3	Below 50.
2143	3	Between 55 and 60.
2117	3	Between 60 and 65.
2053	3	Inconclusive.

The reaction of hen 2084 stands in marked contrast to that of hens 2058 and 2009. Such differences may be due to differences in feather covering or in the amount of subcutaneous fat, or in the vasomotor control of the birds. They represent the penalty of working with several animals rather than with one, in so far as the consistency of the data obtained is concerned.

Although the practical importance of the location of the critical temperature of the fasting farm animal is obvious, it should be realized that it is subject to variations, not only in the animal itself, but in its thermal environment. At constant low temperatures the heat production of an animal may vary with the humidity of the surrounding atmosphere or with the prevalence and intensity of air currents. It is the cooling power of the surrounding air, rather than its temperature alone, that determines whether the heat produced in metabolism is sufficient to maintain body temperature. Investigations concerned with the relative importance of temperature, humidity, and air movement would be of great interest and value.

#### RATE OF INCREASE IN HEAT PRODUCTION OF ANIMALS EXPOSED TO ENVIRONMENTAL TEMPERATURES BELOW THE CRITICAL

Another problem of importance in this connection relates to the rate at which the heat production of an animal will increase per degree fall in the environmental temperature below the critical. It is known that above the critical temperature the emission of heat from the body surface is regulated by vasomotor reflexes, by reflex stimulation of the sweat glands, and at high temperatures by the type of breathing. If it may be assumed that at the critical temperature the radiating capacity of the skin is reduced to the lowest possible minimum by vasoconstriction of the arterioles feeding the subcutaneous capillary bed, and that the secretory activity of the sweat glands has been totally inhibited, it is reasonable to suppose that Newton's law of cooling bodies will apply, and that

$$H = k(t - t^1),$$

where  $H$  is the heat emission (or heat production) at the critical temperature,  $t$  is the normal body temperature of the animal,  $t^1$  the critical environmental temperature, and  $k$  a constant equal to the increase in heat emission (or heat production) per degree drop in temperature. If this equation represents the conditions prevailing,

the increase in heat production with decrease in temperature below the critical should be linear.

The only experimental data that appear to be available for testing the applicability of this equation to animals in environments below the critical are those of Capstick and Wood on the pig.<sup>3</sup> These data indicate a linear increase in heat production with decreasing environmental temperatures below the critical, as the equation would predict. The experimental data also indicate that the increase occurred, in the particular pig observed, at the rate of 0.077 calorie per minute per degree drop (1, p. 265). It is interesting to compute the rate of increase predictable from the above equation. At 20.4° C. (the approximate critical temperature), the basal heat production of the pig, corrected to a weight of 300 pounds, was 1.499 calories per minute. If the body temperature of the pig be taken as 39.5° C. (11, p. 90), the equation becomes

$$1.499 = k (39.5 - 20.4)$$

$$k = 0.078 \text{ calorie.}$$

This value of  $k$ , computed from a theoretical consideration of the conditions prevailing at the critical temperature, is in remarkably close agreement with the value experimentally determined (0.077 calorie) from observations at and below the critical temperature. This agreement, together with the linear character of the rise observed in the heat production as the temperature fell below the critical, may be taken as legitimate confirmation of the applicability of Newton's law of cooling bodies to the relation between the basal heat production of the pig and the environmental temperatures at and below the critical.

If the formula may be assumed to apply to the hen also the practical significance of the value of  $k$  may be illustrated as follows:

A 5-pound hen, according to unpublished data, will possess an average basal heat production of approximately 115 calories per day. If the body temperature of the hen be taken as 106° F. and the critical temperature as 62° Newton's formula becomes

$$115 = k (106 - 62), \text{ and}$$

$$k = 2.6 \text{ calories per degree Fahrenheit.}$$

This means that for each drop of 1° F. in the temperature of the environment below the critical, the heat production of the hen must increase 2.6 calories per day in order to maintain her body temperature. If the hen is moving around actively in a small pen, the writers' data indicate that her heat production may easily be increased by 70 calories daily; the critical temperature of the fasting *active* hen may be computed to be  $62 - (70 \div 2.6) = 35^\circ$ . If the hen is consuming a ration composed largely of corn, sufficient in amount to support an egg production of one per day (estimated to be 0.217 pound), the heating effect of this amount of food may be estimated, from unpublished data, at 51 calories. This amount of heat is sufficient to cause a further drop in critical temperature of about 20°. Therefore, it may be roughly estimated by the use of Newton's con-

<sup>3</sup> In no one of the experiments reported in Table 1 was the critical temperature of the hen located with sufficient definiteness to permit its use in this sort of a calculation.



stant that a 5-pound hen confined to a small pen and receiving a sufficient ration, based mainly on corn, to support the production of one egg a day, could stand an outdoor temperature of 15° before requiring additional food to keep her body warm. Evidently this rough prediction would be too low if the atmosphere were excessively humid, increasing the heat loss from the body by conduction, or if the hen were exposed to a brisk wind, which would have the same effect.

### SUMMARY

From 36 experiments with 12 Rhode Island Red hens, involving 137 determinations of the carbon dioxide production during fast and quiescence at different temperatures, it was found that the average critical temperature was 62° F. This value applies to winter-feathered birds in an atmosphere of low humidity and in an air current of approximately 3 liters per minute. Some of the individual birds appeared to exhibit distinct differences in their reaction to changes in environmental temperature.

It is shown that Newton's law of cooling bodies may apply to animals at environmental temperatures below the critical. The practical significance of this conclusion is discussed and illustrated.

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